Broadband Satellite Communication in EHF Band

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Abstract. The continuous increase in Satellite resources demand, especially in Government and Military missions, led to both efficiently use the Satellite Bandwidth/Power resources, as well as differentiating frequency Bands.

The attractiveness of the highest frequencies in terms of reduced antenna dish size, maintaining terminals with good throughput performances, induced us to develop an EHF DVB-RCS Terminal for Government and Military use. This paper describes the Terminal and Network architecture, the overall performances obtained and the future developments planned in this area.

1 Introduction

The EHF Band is going to be more and more used for Military Satellite application even in Europe, being widely diffused in US.

The Italian Defence Satellite (SICRAL) is one of the first in Europe equipped with an EHF Transponder (44 GHz Up and 20 GHz down) for Telecommunication purposes. The Demo Network that has been set up has several objectives:

- To demonstrate the effectiveness of the EHF band for an IP-switched network based on the DVB-RCS (Digital Video Broadcasting – Return Channel Via Satellite) open standard
- To validate the link analysis in the 44 GHz band
- To validate the Satellite coverage
- To gather elements of propagation statistics at that frequency
- To gather elements of traffic statistics supported by the network

This paper will present the collected results based on the above objectives and will provide a synthesis on the conclusions.

2 Elements of the Trial Network

Figure 1 provides a general overview of the network topology.

The network structure is composed, essentially, by three main Satellite resources in addition to the Terrestrial Back-Bone. The real demo Network was composed

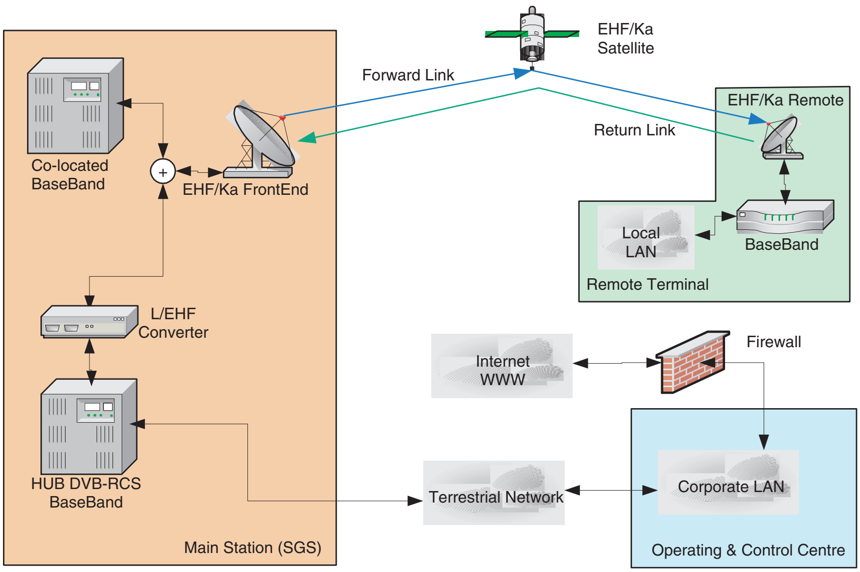

Fig. 1. Network structure.

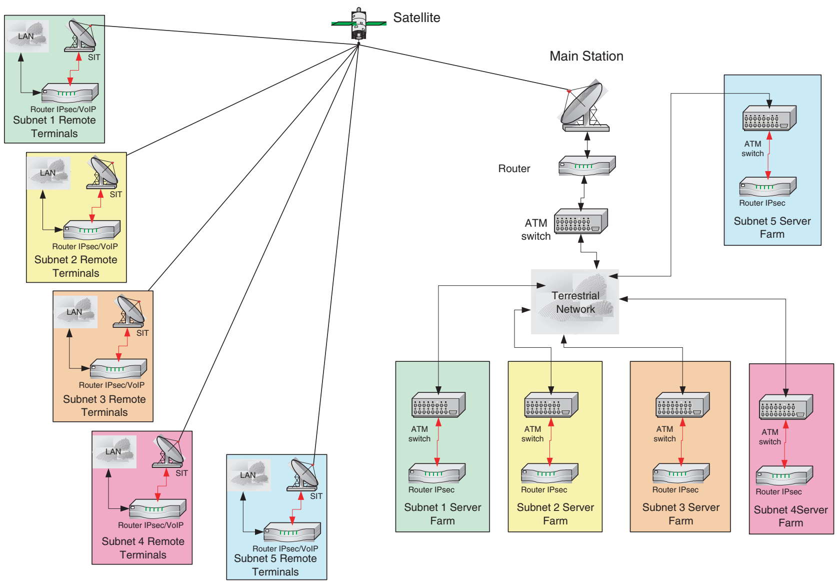

Fig. 2. Sub-networks details.

by 12 remote Terminals, structured in five sub-networks (Fig. 2). Each of these sub-networks was virtually separated by IPsec devices.

Figure 3 illustrates the detailed structure of one of these sub-networks: the IPsec traffic and the GRE tunnel are showed up. The IPsec traffic is exchanged between

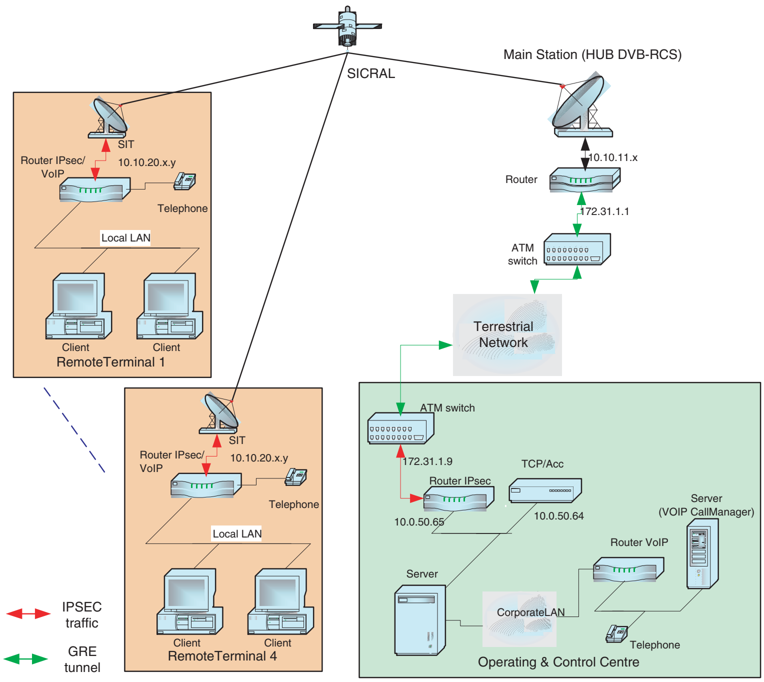

Fig. 3. Sub-network detailed structure.

the remote Terminals and the Operating & Control Centre, passing through the GRE tunnel created in the Main Station.

2.1 The Satellite

SICRAL is Italy's first military satellite, launched in 2001. It has been designed to operate in EHF, SHF and UHF frequency bands with fixed and mobile terminals.

The EHF Transponder of the SICRAL Satellite has been used. The Satellite provides a domestic coverage over Italy and a partial coverage over the east-cost of Europe faced to the Adriatic Sea, in this frequency band.

Figure 4 shows the distribution of the remote Terminals on the territory. The Terminals have been placed in order to cover the edges of the Satellite coverage and to provide a significant set of trials.

Thanks to Italian MoD, enough bandwidth/power has been used for the Trial network to simulate a much bigger network (typically made by more than 500 terminals).

In particular an 8 Mbps Forward Channel and an aggregate of 1.5 Mbps on the Return Channels have been used.

Fig. 4. Terminal distribution on territory.

2.2 The HUB Station

The HUB Station has been based on the available RF Subsystem including the 4.2m Antenna and the dedicated HUB base band. The RF subsystem has been designed to provide UpLink Power Control (UPPC) feature.

UpLink Power Control provides a compensation of the rain fade effects in satellite communications, just increasing the transmission power. In EHF band, the atmospheric effects are a severe problem considering that the attenuation may be many dB high even at moderate rain rates.

The following algorithm is under evaluation to compensate the up link power fading (Fig. 5). It calculates the EHF HPA attenuation to be applied.

At the beginning, an operator inserts the expected beacon levels at clear sky, B_{cc} [dBm] in the Monitor & Control system (M&C).

The Antenna Control Unit (ACU) periodically provides the misured beacon level B_{mis} [dBm] at 20 GHz to the M&C.

The M&C periodically calculates the attenuation level A_{20} [dB] at 20 GHz and the attenuation level A_{44} [dB] at 44 GHz (up link), according to the following formulas:

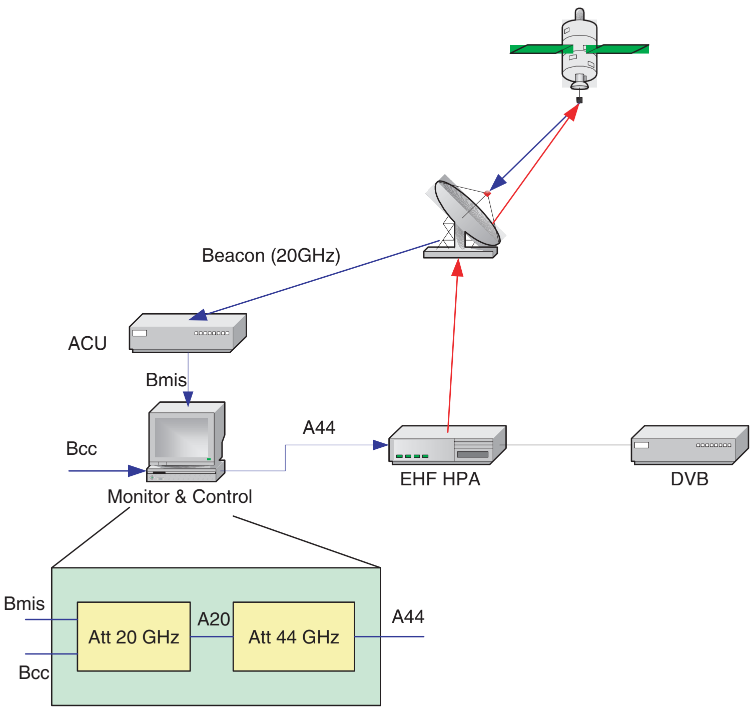

Fig. 5. UPPC scheme.

$$A_{20} = B_{cc} - B_{mis} \tag{1}$$

$$A_{44} = 4 * k_{44}^{*}(A_{20}/4^{*}k_{20})^{\wedge}(\alpha 44/\alpha 20) \tag{2}$$

where:

$$k_{44} = 0.4236, k_{20} = 0.08488, \alpha_{44} = 0.9102, \alpha_{20} = 1.0914 \tag{3}$$

Using (2) the following estimated values of A_{44} are obtained, while the intermediate values can be calculated by linear interpolation.

A_{20} [dB]	A_{44} [dB]
0.1	0.6
0.3	1.5
0.5	2.3
1	4.2
1.5	5.8
2	7.4
3	10.4
4	13.3
5	16

(4)

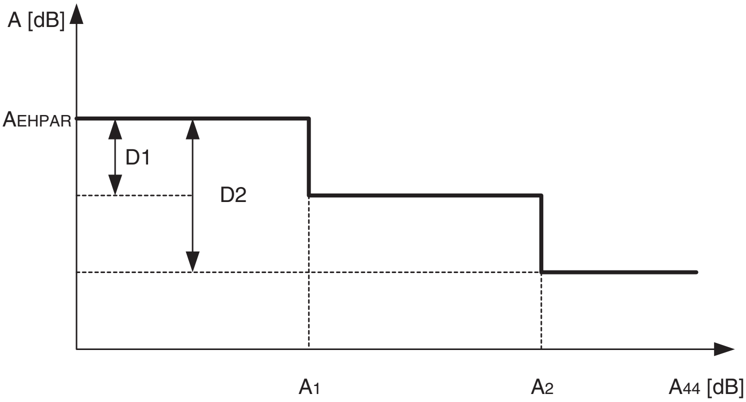

Fig. 6. EHF HPA variable attenuation.

The EHF HPA attenuation A [dB] is then set according to the following rule (Fig. 6), in order to compensate the up link fading:

$$A = A_{EHPAR} \quad \text{if } A_{44} \leq A_1$$
$$A = A_{EHPAR} - D_1 \quad \text{if } A_1 \leq A_{44} \leq A_2$$
$$A = A_{EHPAR} - D_2 \quad D_2 > D_1, \text{if } A_{44} \geq A_2$$

where:
A_{EHPAR} = EHF HPA attenuation in down link rain conditions and up link clear sky (default value 4.7 dB)
A_1 = medium rain threshold, settable parameter (default value 4.7 dB)
A_2 = high rain threshold, settable parameter (default value 7 dB)
D_1 = medium rain EIRP increased value, settable parameter (default value 2 dB)
D_2 = high rain EIRP increased value, settable parameter (default value 4 dB)
Another possible UPPC solution, under evaluation at present, is shown in Fig. 7.

The ACU periodically provides the misured beacon level B_{mis} [dBm] at 20 GHz to the M&C. The down link attenuation A_{dw} can be calculated from this value.

An FDMA modem can be used in loop mode to get the misured E_b/N_0 and to calculate the total attenuation A_{tot}, which is a function of both down link and up link attenuations:

$$A_{tot} = f(A_{up}, A_{dw}) \qquad (6)$$

From the knowledge of A_{tot} and A_{dw}, the up link attenuation A_{up} at 44 GHz can be calculated.

2.3 The Terminal

The Remote Terminal key subsystems are the 1.2m carbon fibre Antenna subsystem, the 31 dBm SSPA at 44 GHz and the Indoor DVB-RCS Modem. The design of the terminal was focused on the overall performances, but primarily on the EIRP, but

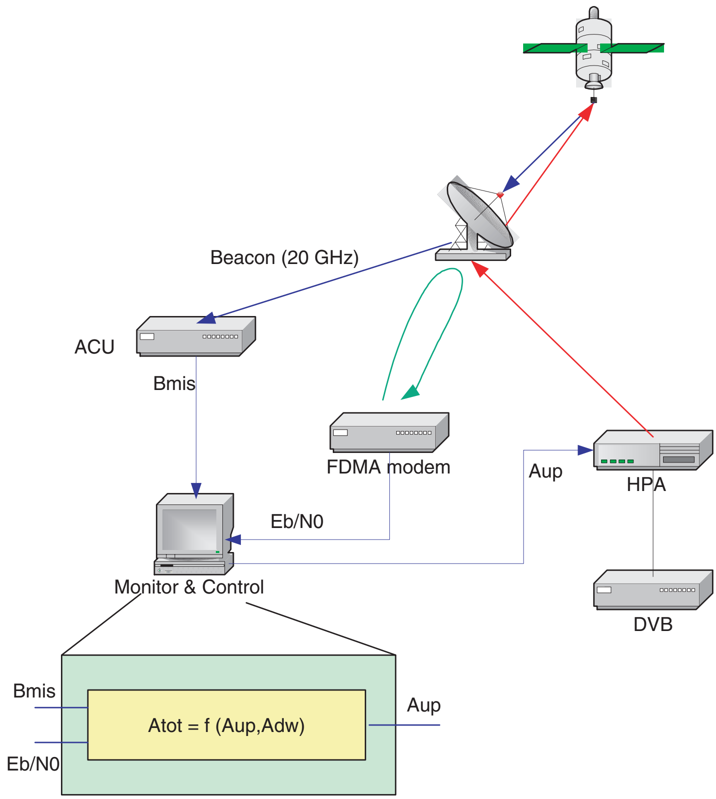

Fig. 7. Alternative UPPC scheme.

maintaining the cost as low as possible. The terminal has been designed to mitigate the heavy propagation fades, by means of two main features: enough EIRP margin and Dynamic Rate Assignment (DRA). This last feature will be explained in the next paragraph.

2.4 DVB-RCS Network Solutions

The EHF Demo network is an IP-switched network based on the DVB-RCS open standard for broadband satellite communications. It provides a two way unbalanced link between Hub and remote Terminals (Forward link from Hub to Terminals and Return link from Terminals to Hub).

The Forward link is a standard DVB-S (Digital Video Broadcasting over Satellite) broadcast channel, based on QPSK modulation, Reed Solomon and convolutional code for Forward Error Correction (FEC), Time Division Multiplexing (TDM) access and MPEG2 Transport Streams for carrying data (user traffic, DVB-S signalling data, DVB-RCS signalling data, network operator monitor & control data.

The Return link is based on a MF-TDMA (Multiple Frequency – Time Division Multiple Access) access scheme, QPSK modulation, and Reed Solomon and convolutional code or Turbo coding FEC, MPEG2 or ATM burst profiles.

A protocol stack for Forward and Return links is provided in Fig. 8 and a simplified scheme of DVB-RCS principles of operation is illustrated in Fig. 9.

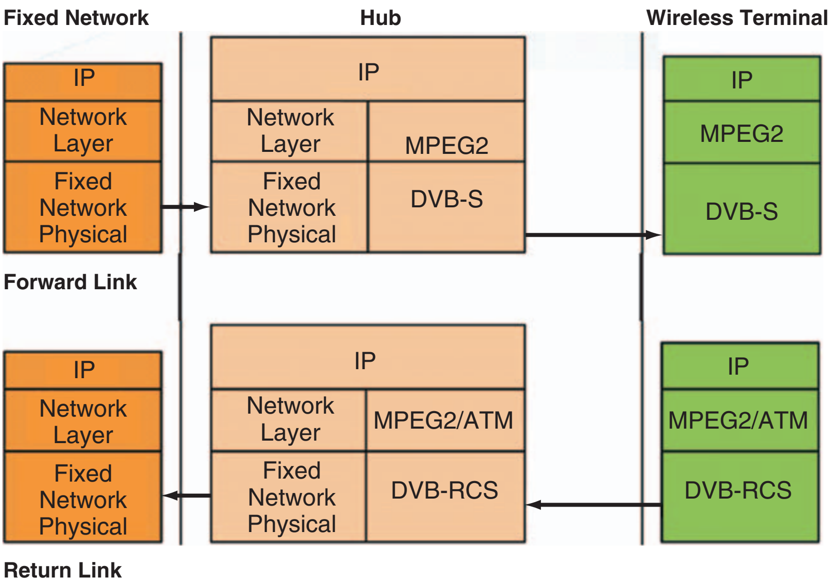

Fig. 8. Protocol stacks (forward and return links).

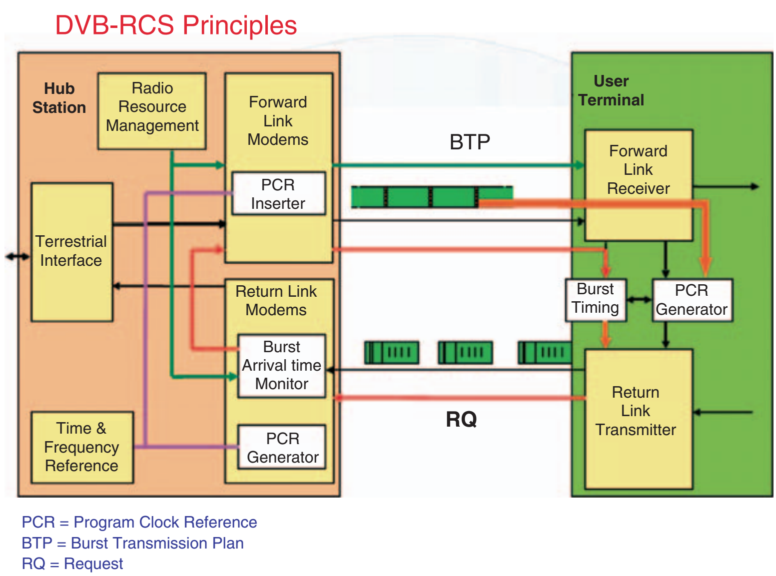

Fig. 9. DVB-RCS principles.

2.4.1 Dynamic Rate Assignment (DRA). The Return link access scheme can operate in two different ways: fixed or dynamic slot MF-TDMA. In fixed slot MF-TDMA, the bandwidth and duration of successive slots are fixed.

In order to reduce the effects of EHF propagation fading, the MF-TDMA slots are dynamically assigned. This means that the Terminal can change frequency, bit rate, FEC-rate and burst length from burst to burst, depending on the link properties (Fig. 10) or the congestion on the network (DRA).

All the Terminals are equipped with a fast frequency hopping feature to achieve the DRA.

2.4.2 TCP Over Large Delay Network. A satellite network is characterized by a large delay (about 550–600 ms round-trip delay) and this aspect limits the TCP speed. Many solutions have been adopted to overcome this problem.

One solution is to introduce a TCP accelerator server in the Hub and a TCP accelerator agent in each Terminal. The TCP accelerator ends the standard TCP protocol sending an "ACK" message to the terrestrial side and uses a satellite optimised protocol over satellite (Fig. 11). Using this solution, a very high speed on FTP download is achieved (tens of Mbps).

The problem with this kind of solution is related with security. The encryption of TCP headers makes impossible to use a TCP accelerator.

For this reason, the above solution has been rejected, while the solution adopted during the trials consists in modifying the TCP Receive Window Size.

The TCP bandwidth depends on the Receive Window Size and the Satellite Round Trip Delay.

With a default window of 64 Kbytes and a Satellite Round Trip Delay of 600 ms, the maximum possible bandwidth is little less than 900 Kbps, but increasing the

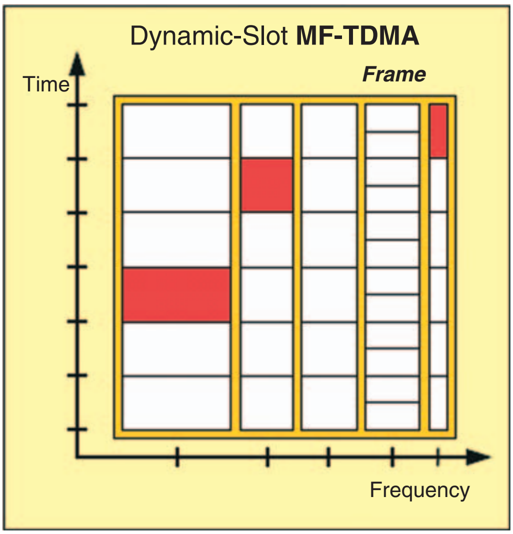

Fig. 10. Dynamic slot MF-TDMA scheme.

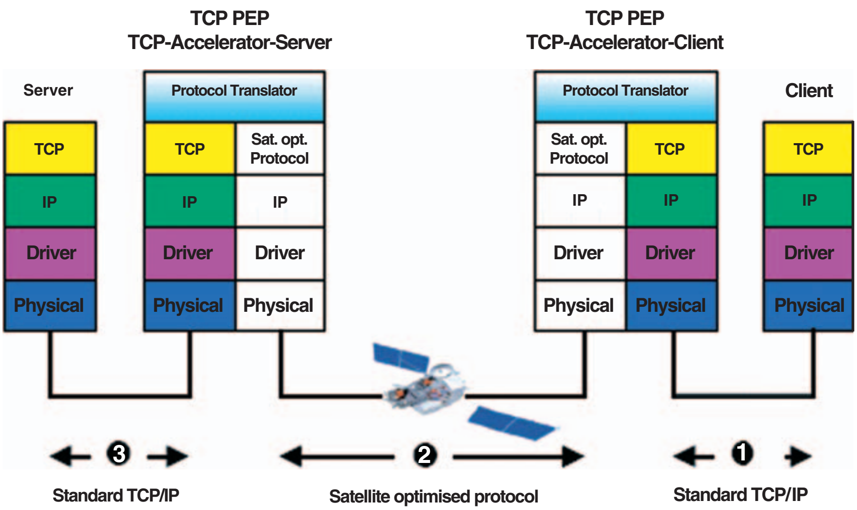

Fig. 11. TCP acceleration.

window up to 256 Kbytes with the same Satellite Round Trip Delay the maximum bandwidth is almost 3.5 Mbps.

3 Trials Results

The results obtained during the trials are provided in the following sections.

3.1 Link Results

The following figures illustrates how the Return link carrier type varies, trying to follow and to compensate the E_s/N_0 changes, thus implementing the Dynamic Rate Assignment.

When the E_s/N_0 decreases, the system tries to overcome the worse link conditions and it selects lower bit rate carriers.

Figures 12–14 show the results obtained for Site 1, which is located in the middle of Italy and of the satellite coverage, while Figs. 16 and 17 shows the data of Site 2, which is located beyond the edge of the satellite coverage. Both the sites were under variable weather conditions.

The meteorological observed conditions of Site 1 are given in Fig. 15, those of Site 2 are given in Fig. 18.

A steady fair weather, on the contrary, gives a quite constant value of E_s/N_0 and a constant value of the carrier type as a consequence, as shown in Fig. 19 of Site 3, which is located in the north of Italy.

The analysis of the traffic data during a period of more than three months provides the Service Interruption graphic of Fig. 20.

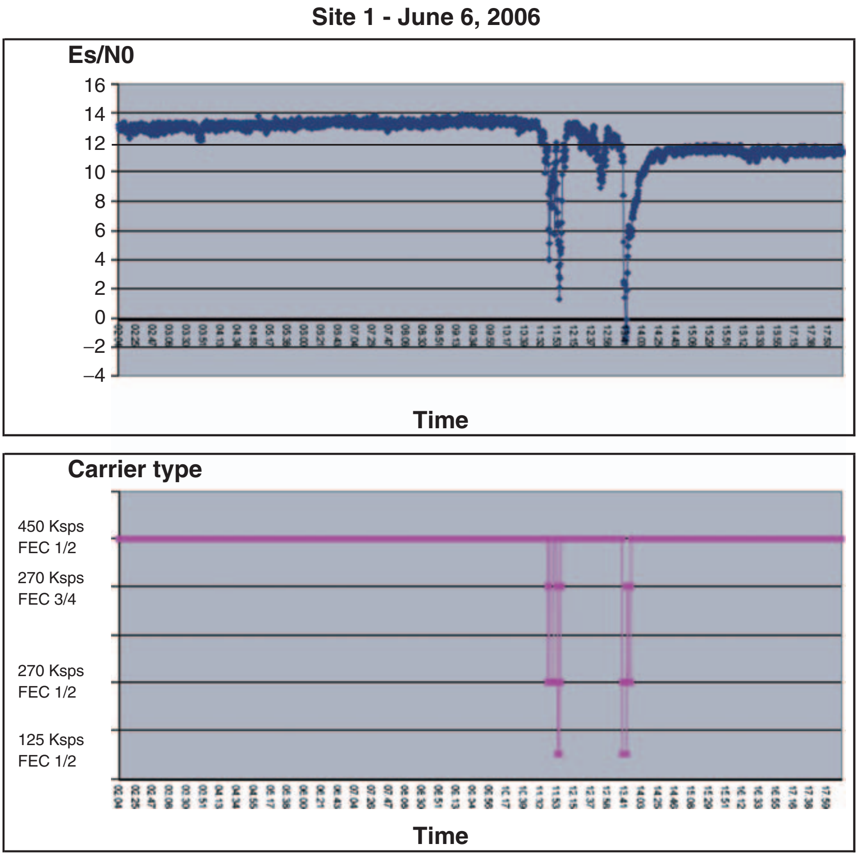

Fig. 12. Site 1 link statistic.

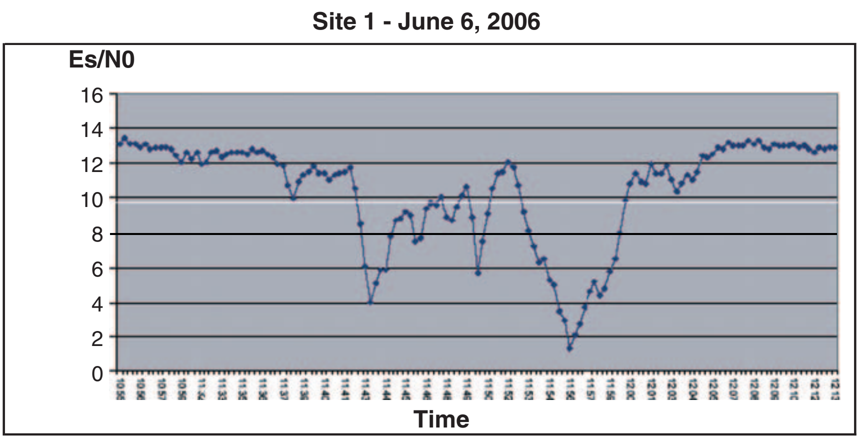

Fig. 13. Site 1 link statistic (details – first section).

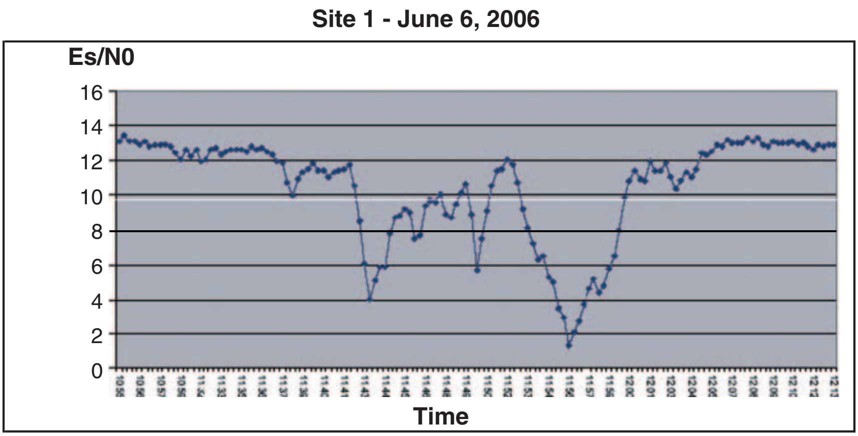

Fig. 13. (*Continued*) Site 1 link statistic (details – first section).

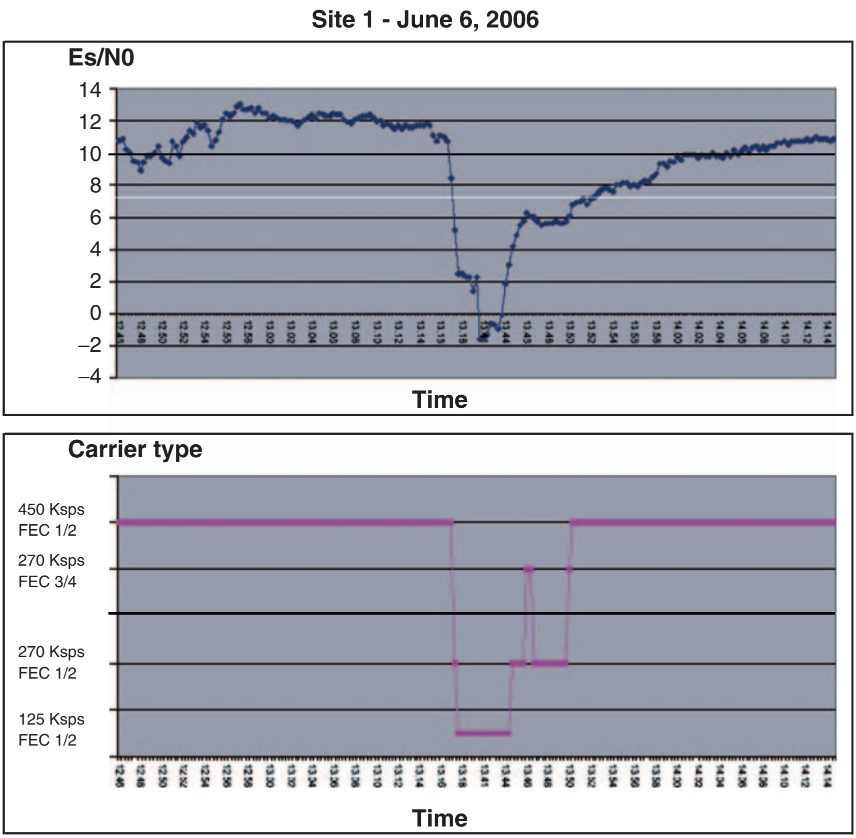

Fig. 14. Site 1 link statistic (details – second section).

Site 1

June 6, 2006

UTC	MSLP hPa	TEMP °C	RELH %	WIND knots	VIS	SKY	SIGWX
07.50	1020	19	68	SSE-8	Good	Overcast	-
08.20	1021	19	68	S-7	Good	Overcast	-
08.50	1020	19	68	SSE-9	Good	Overcast	Light rain shower
09.20	1020	19	72	SSE-8	Moderate	Overcast	Thunderstorm
10.20	1021	16	72	NE-6	Moderate	Overcast	Thunderstorm
11.20	1021	14	82	WSW-6	Moderate	Overcast	Thunderstorm
11.50	1021	14	82	N-8	-	Overcast	Light thunderstorm rain
12.20	1020	14	82	NNE-4	Moderate	Overcast	Thunderstorm
13.20	1021	14	82	N-8	Poor	Very cloudy	Rain shower
13.50	1021	13	82	NNE-11	Poor	Very cloudy	Rain shower
14.20	1020	13	82	NE-8	Poor	Overcast	Light rain shower
14.50	1020	14	76	VAR-3	Good	Overcast	-
15.20	1020	15	77	S-5	Moderate	Overcast	-
15.50	1019	16	67	SW-4	Good	Overcast	-
16.20	1019	17	67	W-6	Good	Scattered clouds	-

Fig. 15. Site 1 meteorological information

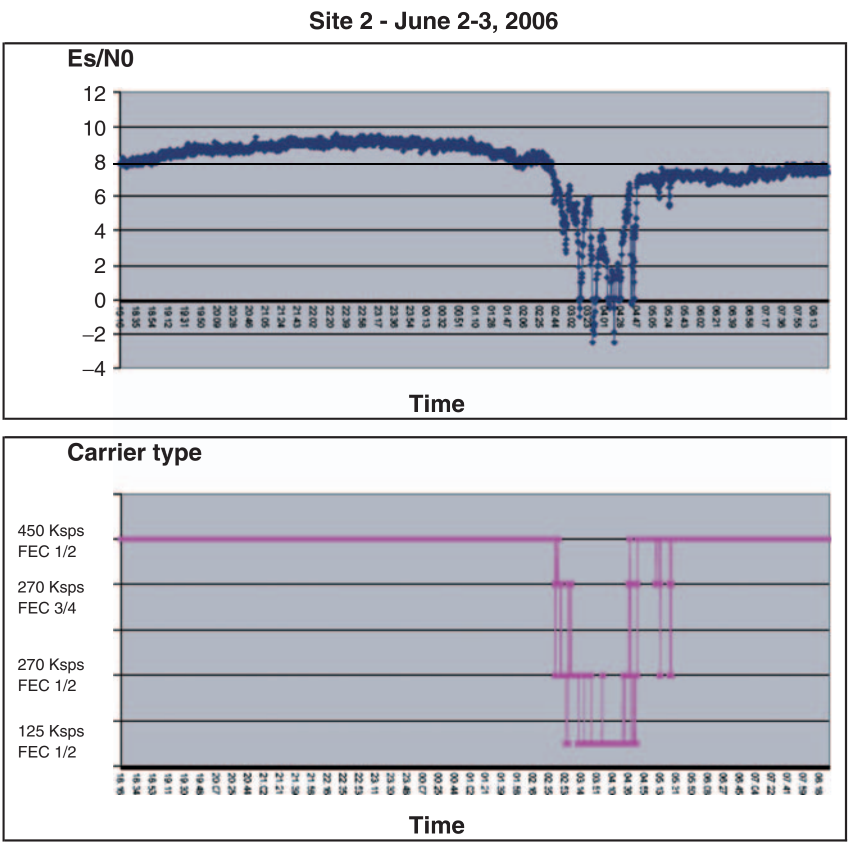

Fig. 16. Site 2 link statistic.

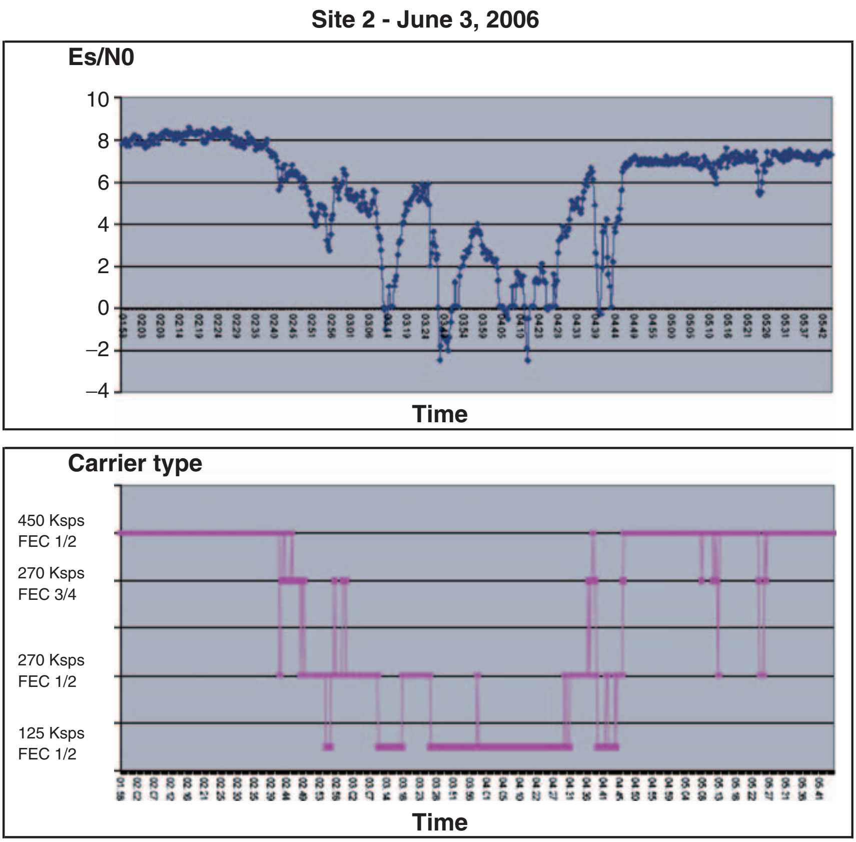

Fig. 17. Site 2 link statistic (details).

Site 2 neighbourhood

June 3, 2006

UTC	MSLP hPa	TEMP °C	RELH %	WIND knots	VIS	SKY	SIGWX
04.00	1011	14	100	W-8	Moderate	Overcast	Heavy thunderstorm rain
05.00	1012	12	100	SSW-8	Moderate	Overcast	Heavy thunderstorm rain
06.00	1011	12	100	E-10	-	Overcast	-
08.00	1010	18	93	SE-12	Good	Scattered clouds	-

Fig. 18. Site 2 neighbourhood meteorological information.

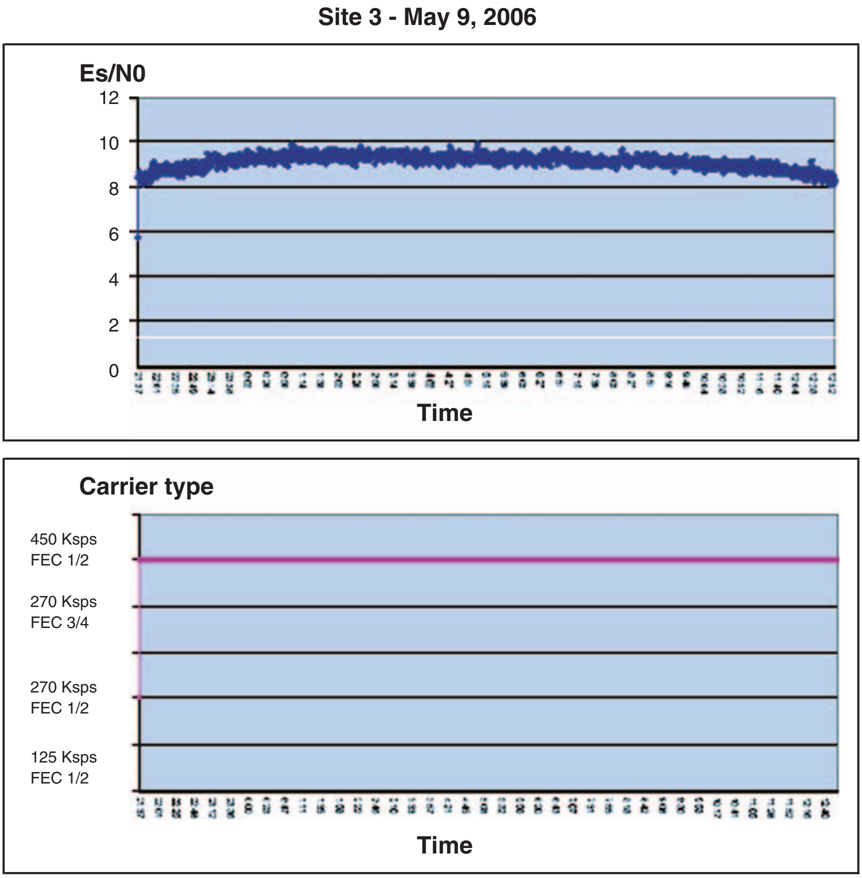

Fig. 19. Site 3 link statistic.

Four sites have been considered, which are located in different areas covered by the satellite, characterized by different meteorological conditions and landscape.

The total amount of Service Interruptions, expressed in hours and minutes, and the percentage of Service Availability of each site is provided in the following table.

It must be noticed that the Service Availability is at least more than 99%, considering that the observation window includes spring months, which are usually characterized by large amounts of precipitation.

Observation Window March 3 - June 9, 2006

	Location	Service interruptions (hh:mm)	Service availability (%)
Site 1	South	3:15	99.86%
Site 2	North	8:56	99.61%
Site 3(*)	Northwest	19:12	99.17%
Site 4	Middle	9:07	99.60%

(*) rainy zone

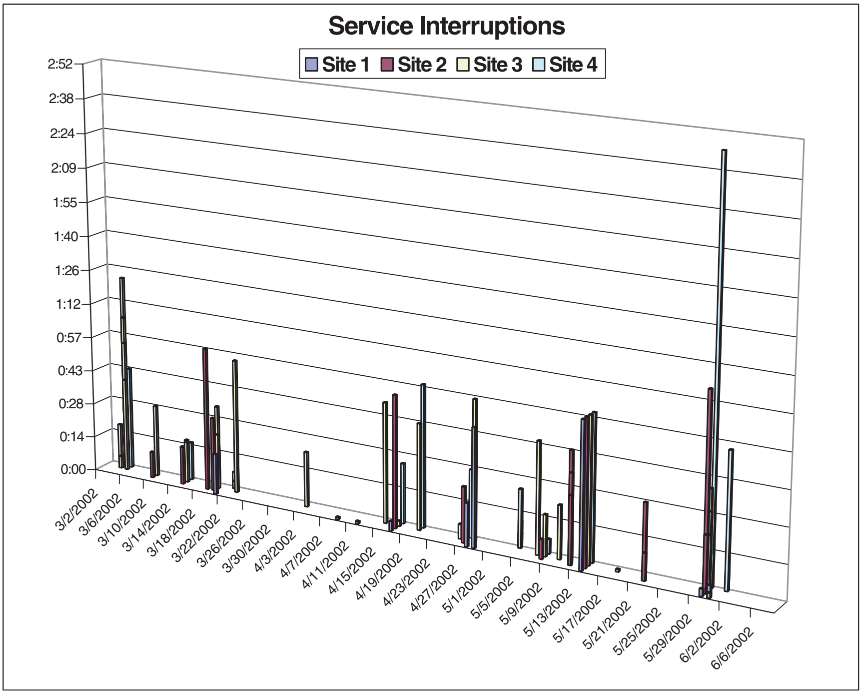

Fig. 20. Service interruptions (hh:mm).

3.2 Throughput Analysis

Several tests on throughput performances have been carried out during the trial period: in the following table a synthesis of the main results is provided.

Throughput Performances

	TCP standard		TCP enhanced	
Application	Forward (Download)	Return (Upload)	Forward (Download)	Return (Upload)
FTP	850 Kbps	248 Kbps	1,3 Mbps	250 Kbps
Internet Download	800 Kbps	240 Kbps	1,3 Mbps	250 Kbps

The Table shows the performances obtained with various protocols (application) with both standard TCP parameters and optimized TCP (using the TCP Receive Window Size method). To be noted that the Return link throughput is limited by the Satellite Channel Rate (in this case limited to 300 Kbps), while the Forward link is limited by the Receive Window Size and Satellite Round Trip Delay, as described above.

3.3 Traffic Analysis

Three QoS (Quality of Services) categories for assignment capacity in the return link have been treated:

- CRA
- VoIP bandwidth on demand (BoD VoIP)
- Best effort (BE) bandwidth on demand (BoD BE)

During the trials several traffic traces have been captured: Figure 21 shows an example of the observation window of the peak capacity requested by a single terminal during a window of several days.

The traffic analysis performed is particularly important to gather information useful to dimension the overall Network throughput for each of the services provided.

4 Conclusions and Future Steps

Taking into account the link results, the Service Availability statistics and the throughput analysis, the trials results confirm the validity and the potentiality of the EHF band for an IP-switched network based on the DVB-RCS open standard.

Some improvements on this type of technology applied in Military environment are requested to better fulfil the specific user's requirements and particularly:

- To fit a non-homogeneous network (based on different Terminal size and capacity). There is the need to have more Forward links at different bit rates: it is clear that very small Terminals cannot manage too much high bit rates.

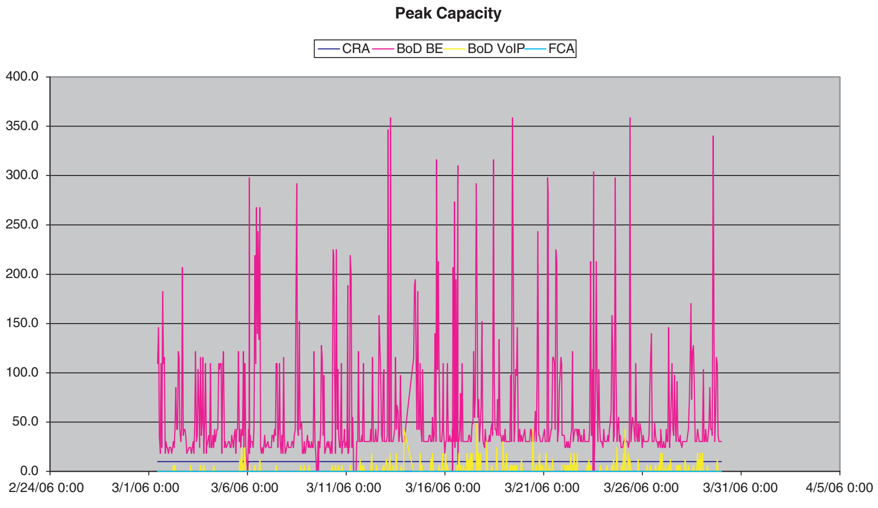

Fig. 21. Traffic peak capacity (Kbps).

- To introduce the meshed topology for peer-to-peer direct connection. If two Terminals have to exchange data (a typical example consists in a VoIP connection), a double satellite hope is necessary at the moment, passing through the Hub and with all the related disadvantages. A meshed topology will eliminate double hope, just connecting together the two Terminals.
- To have a communicating On-the-Move Terminal.

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